The Reading of Rotated Text – An Embodied Account

by

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ABSTRACT

Individuals engaged in perceptual tasks often use their bodies to lighten the cognitive load, that is, they replace internal (mental) processing with external (body-based) processing. The present investigation explores how the body is used in the task of reading rotated text. The experimental design allowed the participants to exhibit spontaneous behavior and choose what strategies to use in order to efficiently complete the task. The results demonstrate that the use of external strategies can benefit performance by offloading internal processing.

DEDICATION

To my wife Laura.

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INTRODUCTION

Cognition was traditionally seen as situated inside the head. Embodied cognition, a relatively new trend in cognitive science, represents an alternative to this view. According to Glenberg (2010), the embodiment framework has the potential to become a unifying paradigm in psychology since all psychological processes are influenced by "dynamic interactions of behavior brain, bodily processes, and changes in the physical and social world" (p. 594). One of the central topics of the embodied cognitive science paradigm is the question of whether individuals can replace internal processing by moving their bodies and/or manipulating their environment. This strategy is referred to as cognitive offloading (Clark, 2011; Wilson, 2002). Examples of cognitive offloading include the use of gestures while talking to offload working memory (e.g., Cook, Yip & Goldin-Meadow, S., 2012) and storing information in the environment instead of the mind (e.g., Sparrow, Liu & Wegner, 2011). The present investigation uses a natural behavior approach to investigate cognitive offloading during the reading of rotated text.

The Reading of Rotated Text

Various studies have explored the question of how individuals name or read rotated letters, words or text. Jolicoeur and Landau (1984) demonstrated that there was a linear increase in errors in identifying single letters with an increase in angular deviation from the standard canonical orientation. Thus, it is easier to identify letters when they are presented in their canonical (i.e., upright) orientation than when they are rotated. The same pattern is present for rotated letter strings. Koriat and Norman (1984) showed strong effects of angular deviation of letter-arrays on lexical decision times, with the mean response times increasing with the increase in angular deviation from the upright position. In a similar vein, Navon (1978) demonstrated that rotation influenced single word reading speed and Byrne (2002) reported that reading marquee words (i.e., vertically presented words with letters in canonical orientation cascading down) was the most difficult of all of the various spatial transformations.

Beyond single letters and words, Tinker (1956) explored the influence of the angular deviation of paragraphs on reading speed. He reported a significant decrease in reading speed when participants read paragraphs presented rotated 45-degrees (to the left or to the right) compared to their reading of upright paragraphs. The presentation of paragraphs rotated 90 degrees led to a further decrease in response time. Similar findings were reported by Brown et al. (1989), Graf and Levy (1984) and Wigdor and Balakrishnan (2005). Thus, rotation influences the reading of letter arrays, single words, and connected text in such way that reading speed decreases with the increase in the angular deviation of presented stimuli.

Previous research has also demonstrated that the reading of rotated text was related to the complexity of the stimulus, which is determined by the number of items (ranging from single letters to connected text). For example, when participants read single words and short phrases rotated 45-degrees, reading speed decreased 7% and 10% respectively, while in the 90-degree orientation, the corresponding penalties increased to 26% and 54% (Wigdor & Balakrishnan, 2005). Thus, the increase in the angular deviation taxed the reading of short phrases more than the reading of single words. Taken together, previous research has demonstrated that there is a decrease in reading speed that corresponds with an increase in the angular deviation of the presented stimulus and that more complex stimuli (e.g., connected text) are affected more by stimulus rotation than the rotated simple stimuli (i.e., single letters and letter arrays). The current study will investigate the potential of transferring some of the costs associated with text rotation onto the body – a form of cognitive offloading.

Cognitive Offloading

Cognitive offloading is defined as the trading off of internal processing for external processing. By offloading cognitive work to the body or environment, individuals can putatively increase their efficiency in various tasks. The possibilities of dynamic couplings of the mind and the body and external world are numerous. Wilson and Clark (2009) have argued that the right kind of coupling leads to the extension of one's cognitive apparatus. Examples of coupling include using natural resources (e.g., the environment), technological resources (e.g., various instruments) and socio-cultural systems (e.g., writing systems) to lighten the internal cognitive load. All these resources can potentially augment our internal processes and become functional parts of the cognitive system.

Previous research has investigated cognitive offloading in various contexts. For example, Kirsch (1995) reported that during the computer game Tetris players physically manipulated the environment by rotating blocks on the screen, which lead to mental savings. While the physical rotation of the blocks took around 150ms, the mental rotation of those blocks would have taken between 750 and 1500ms. In a similar vein, a study by Goldin-Meadow, Nusbaum, Kelly, and Wagner (2001) demonstrated that using gestures while explaining math could offload working memory demands. Participants first solved a math problem, and then had to memorize either a short or a long list of items (letters or words). Afterwards, they were asked to explain how they solved the math problem. Critically, one group was allowed to gesture while giving the explanation whereas the other group was asked not to gesture. After the explanation, participants recalled the letter strings or words. The group that was allowed to gesture while giving the explanations recalled more items from the memory task than the group that was not allowed to gesture. Thus, gestures increased available cognitive resources.

A potential alternative to this offloading account could be that the participants that were asked not to gesture had had their performance on the working memory task impaired because they had to continually remember what to do (i.e., remain still). To explore this possibility, the authors separately analyzed the data of the speakers in the gesture condition who had chosen not to gesture. The results demonstrated that participants who gestured recalled more on long lists, which taxed working memory more, compared to those who chose not to gesture. This confirmed that the instructions in the no gesture group did not influence the results. Thus, gestures can offload working memory. Similar results were demonstrated by Kessell and Tversky (2005) and Ping and Goldin-Meadow (2010).

Another way to offload cognitive processes is by using the environment as a form of external memory storage. For example, by simply using a pencil and a piece of paper while solving a mathematical problem, individuals can offload costly internal processing (i.e., solving the problem in the head) to the environment. In an empirical investigation of individual's reliance on the external environment in a memory task, Sparrow et al. (2011) asked participants to read and then type 40 trivia statements. One group of participants was told that the computer would save the typed text and the other group was told that the text would be erased. Additionally, half of the participants in both groups were asked to remember the statements they typed. The results revealed that the participants who believed that the text would not be saved recalled more statements than the participants who believed that the computer would store the text regardless of whether they were instructed to remember the text. This finding suggests that the "computer save" group expended less effort to remember the statements provided they thought that the information was going to be stored in the computer's memory and be available to them (i.e., "When we need it, we will look it up," p. 777). Thus, individuals will often use the environment rather than their memory to store information presumably in order to circumvent costly internal processing. Like language and memory, reading rotated text is another task that provides an opportunity to use the body in order to lighten the cognitive load.

External Alignment

External alignment is a strategy whereby individuals use their bodies when faced with the task of identifying rotated stimuli. According to Wexler et al. (1998), people will often physically move a stimulus to its canonical orientation, or, in cases when the stimulus cannot be moved, turn their bodies in the direction of the stimulus. Previous studies of external alignment explored rotating the eyes in the direction of tilted words (Pashler, Ramachandran & Becker, 2006) and moving the head in the direction of rotated letters or letter arrays (Risko et al., in press). In Pashler et al. (2006) torsional eye movements were observed when participants attended to rotated words. Even though the eyes rotated in the direction of the tilted stimuli, the authors maintained that the function of those movements was "puzzling" (p. 957), as the eye rotation alone was unlikely to have reduced the cost of text rotation. Risko et al. (in press) studied larger external alignments. Their study found that the likelihood of head tilting in the task of reading rotated letters and letter arrays was related to the difficulty of the task (i.e., the frequency of head tilting increased when participants read the rotated 15-letter arrays compared to the rotated single letters). This result is consistent with the idea that individuals will use their bodies or the environment to reduce the cost of internal processing. The use of more complex stimuli increased the cost of internal processing and led to more frequent head tilting.

Importantly for the present research, Risko et al. (in press) demonstrated that the use of external alignment did not have an appreciable effect on the ability to read rotated letters. Specifically, when performance in an experiment where head tilting was allowed was compared to the results of an experiment where head movements were restricted, no benefit of head tilting on performance was found. This lack of benefit could mean that there was no cognitive offloading, that is, the same internal processes could have unfolded regardless of the presence/absence of external alignment.

One potential explanation for the negligible benefits of external alignment in Risko et al. (in press) is that the cost of stimulus rotation was small relative to the costs of physical rotation (i.e., the stimuli were single letters and short letter-arrays rather than texts). As noted above, previous research (e.g., Wigdor & Balakrishnan, 2005) has demonstrated that the cost of stimulus rotation increases with stimulus complexity. Given letter-arrays represent relatively simple stimuli, the negligible cost of rotation seems reasonable. Thus, in previous studies the function of external alignment has remained unclear. To further investigate this function, the current study employs head tilting as an external strategy used in the task of reading rotated paragraphs – a stimulus for which a large cost of stimulus rotation is expected.

The Natural Behavior Approach

The investigation of cognitive offloading often involves studying natural behavior that can occur spontaneously in a controlled experiment. Studying natural behavior in the context of a cognitive task allows for the observation of the complex interaction of the mind, the body and the environment. External alignment (i.e., head tilting) during the reading of rotated text reflects just such a natural behavior. Investigation of such behavior requires a more ethological/ethnographic approach (Hutchins, 1995; Kelso, 1995; Risko & Kingstone, 2011; Tinbergen 1963). This approach is often utilized in studies of embodied cognition (e.g., Goldin-Meadow et al., 2001; Gray & Fu, 2004), because it allows the observation of naturally occurring behavior. By observing such behavior, and contrasting its effects on performance in a cognitive task to the effects of more restricted contexts (i.e., where that behavior is not allowed), we can uncover its cognitive function. In order for natural behavior to occur in a controlled experiment, the cognitive task is constrained (e.g., participants read texts presented in various angular deviations), while the participants' behavior is (relatively) unconstrained (e.g., participants are allowed to move their heads freely). Observing the participants' behavior during the task of reading rotated text allows us to analyze how they use their bodies and the environment to complete the task.

The current study manipulated participants' behavior by allowing or restricting head tilting during the task of reading rotated paragraphs. The function of head tilting was explored by comparing the performance across different conditions. A similar design was previously used in studies that explored the function of gestures (e.g., Goldin-Meadow et al., 2001; Cook et al., 2012). For example, Goldin-Meadow et al. (2001) found that gestures can affect working memory by comparing performance in conditions where gestures were either allowed or restricted during a memory task.

Present Investigation

The purpose of the present study is to investigate the function of external alignment during the reading of rotated text. Risko et al. (in press) demonstrated that the likelihood of external alignment was related to the difficulty of the task. In their study, participants were asked to read one-, five- and fifteen-letter arrays presented at different angular orientations. Participants' movements were either free or restricted. In the free condition, participants were not given any instructions about body movements. In the restricted condition, participants were instructed not to tilt their heads. The study showed that the likelihood of external alignment (i.e., head tilting) in the free condition was related to the cost of stimulus rotation. For example, participants were more likely to rotate when presented with a rotated 15-letter array than with a rotated single letter. While these findings demonstrated that external alignment was systematically related to internal costs (i.e. the cost of mental rotation), the function of the external alignment was unclear. Comparison of the rotation effects among different conditions demonstrated that there were no benefits in terms of response time (RT) or accuracy of such external alignment.

The function of external alignment is important to consider in the context of cognitive offloading, because such a pattern would provide evidence that external alignment replaces internal processing. In other words, one way to demonstrate that external alignment can offload internal processing is by showing that it benefits performance. If external alignment does not improve performance, then there is a possibility that there is no actual trade-off between internal and external processing occurring. If that were the case, then internal processing would not be affected by the behavior, that is, it would remain the same whether the participants were tilting their heads or not. However, if the behavior benefits performance, then the idea that internal processing is offloaded would be supported.

It is important to note that cognitive offloading does not have to necessarily benefit performance. For example, in the task of reading rotated text, there is the possibility that external alignment might offload internal processing, but the time it takes to tilt the head may be longer than the time needed for internal processing. In this case, cognitive offloading would not benefit performance (in terms of RT), even though it replaced internal processing. Thus, in order to find evidence for a benefit it is important to investigate the behavior with a stimulus that leads to a large cost (as we do here). The current study's goal is to explore whether external alignment can replace internal processing in the task of reading rotated text. This is done by investigating the potential of external alignment to benefit performance in such a task.

Chapter 2

EXPERIMENT

The current study explored the potential benefit/cost of external alignment during the task of reading rotated text. Participants were asked to read aloud paragraphs presented either in their canonical orientation (i.e., upright), or rotated 60 degrees to the left or to the right. Compared to one-, five- and fifteen-letter arrays (as used in Risko et al., in press), paragraphs represent more complex stimuli and are expected to lead to more frequent head tilting and a larger cost of stimulus rotation. We can test this assumption by comparing the frequency of head tilting in the Free condition to the frequency of head tilting reported in Risko et al. (in press). In the present study, there were three conditions: Free (i.e., head tilt allowed), Still, (i.e., no head tilt allowed) and Forced Rotation (i.e., participants were asked to tilt their head in the direction of the stimuli). The comparison of performance across these different conditions will shed light on the function of external alignment. A cognitive offloading account predicts that the cost of stimulus rotation will be smaller in the Free and Forced Rotation conditions compared to the Still condition. In other words, demonstrating the benefit of head tilting would support the cognitive offloading account. If there is no benefit of head tilting, then there is the possibility that such behavior is not replacing any internal process. This result, of course, would leave open the question of why individuals would rotate if not to benefit performance.

Method

Participants. Participants were 24 Arizona State University students. The students received either research credit or $10.

Design. A 3 (Conditions: Free, Still, Forced Rotation) x 2 (Angular deviation: 0, 60 degree to the left and the right) within subject design was used. Condition was blocked and the order was counterbalanced. Angular deviation was randomly mixed within blocks. All participants underwent all three conditions.

Apparatus. Stimulus presentation and button response collection was handled by Experiment Builder software (SR Research). The stimuli were presented on a 24" computer monitor. Participants sat 75 cm away from the screen. Two cameras recorded the participants and the screen (see Figure 1 for example frames from video recordings). Participants manually responded by pressing the spacebar on a standard computer keyboard. Participants held the keyboard on their lap.

Stimuli. Ninety paragraphs, consisting of 40 to 52 words arranged in 7 rows, were collected from the NPR website (http://www.npr.org/). The same source of the paragraphs was used to ensure similar difficulty levels. Each condition consisted of 30 counterbalanced paragraphs. The paragraphs were presented centrally in their canonical orientation or rotated 60 degrees to the left or to the right (see Figure 2 for examples). All the stimuli were presented in size 18 Calibri font. The stimuli subtended 4.2° horizontally and 8.4° vertically (on average).

Procedure. Every condition had specific instructions with respect to head tilt. In the Free condition, participants were free to tilt their heads, in the Still condition they were asked not to move their heads (i.e., hold their heads upright), and in the Forced Rotation condition they were asked to tilt their heads in the direction of the stimulus. In every condition participants were instructed to read the paragraphs aloud as quickly and accurately as possible and to press the spacebar when finished. The participants were presented with a single paragraph on every trial. The experiment took around 45 minutes to complete and short breaks were allowed between the blocks.

There was a fourth condition (i.e., Cue condition) in the experiment. In this condition, the participants were asked to tilt their heads to match the upcoming paragraph. This was done by presenting the words “left”, “right” or “upright” before the paragraph presentation. Since this condition used a separate paragraph set, it was not included in the analysis. That said, the results of the analysis of this condition were consistent with the results reported in the text. Specifically, the rotation effects in RT were significantly smaller than in the Still condition.

Chapter 3

DATA ANALYSIS AND RESULTS

The video recording of the testing session was used to determine head tilt in the Free condition. Individual coders were blind to the condition (i.e., they could not see the stimulus image). Head tilts were defined as tilt of 10 degrees or more to the left or to the right that occurred within 1000 ms of stimulus presentation. Although the possibility exists that the magnitude of head tilt might influence performance (in fact this is likely), this question was not in the scope of the current study. Addressing this question will be important for future research and will likely require more detailed recording of head tilt (e.g., motion/head tracking as opposed to video based judgments).

In order to determine intra-observer and inter-observer reliability, 20% of the video recordings were recoded by the same coder and by another coder. Intra-observer and inter-observer reliabilities were high (K = .96 and K = .85 respectively). Response times (RT) represented the amount of time between the presentation of the paragraph and the participants indicating that they were finished reading by pressing the spacebar. Outliers were removed by excluding RTs 2.5 standard deviations above or below participants' mean in a given condition. This procedure lead to the removal in 0.5% of correct trials. Additional removed trials included 2.7% of trials in which the participants pressed the spacebar before they finished reading the paragraphs and two trials removed from eight participants because a paragraph was repeated due to a programing error. Transcription of the recordings was used to determine errors. The first 3 trials in each block were considered practice.

Physical Rotation. A 2 (Angular Deviation: 0 vs. 60) within subjects ANOVA was conducted. There was a significant effect of angular deviation, $F(1, 23) = 99.38$, $MSE = 485.39$, $p < .001$, $\eta_p^2 = .81$. When the stimulus was rotated, the frequency of head tilt was 71.4% and when the stimulus was upright, the frequency was 8.0%. Some of the head tilting observed during presentation of the upright paragraphs stemmed from the participants' moving their heads back to the upright position after reading the rotated paragraphs. In a second analysis we only included the trials in which the participants started with their head upright when the paragraphs were presented in their canonical orientation. In addition, the data for the rotated stimuli was considered only for cases when the participants' starting head position did not match the paragraph orientation. Again, there was a significant effect of angular deviation, $F(1, 23) = 164.14$, $MSE = 411.99$, $p < .001$, $\eta_p^2 = .87$. When the stimuli were rotated, the frequency of head tilt was 75.5% and when the stimuli were upright, the frequency was 0.5%. The percentage of trials on which participants tilted head was higher than in Risko et al. (in press), where the mean frequency of head tilting for the rotated single letters was 3.5% and 2.4% (for the 45 and 90 degree orientations respectively). The corresponding frequencies for the rotated 5-letter arrays were 11.4% and 24.4%, while the values for the 15-letter arrays were 21.0% and 34% (see Figure 3 for comparison of physical rotation frequencies). This is consistent with the idea that the increase in the cost of stimulus rotation will lead to the increased frequency of head tilting.

RT. A 3 (Condition: Free vs. Still vs. Forced rotation) x 2 (Angular Deviation: 0 vs. 60) within subjects ANOVA was conducted. There was no main effect of condition on RT, $F(2, 23) = .96$, $MSE = 841664.83$, $p = .387$, $\eta_p^2 = .04$. There was a main effect of angular deviation, $F(1, 23) = 21.14$, $MSE = 1096220.16$, $p <$

.001, η_p^2 = .47. In addition, there was an interaction between condition and angular deviation, $F(2, 46) = 5.77$, $MSE = 470747.26$, $p = .006$, $\eta_p^2 = .20$ (see Figure 4 for the actual values). The slope of the function relating angular deviation and RT was calculated to compare the influence of paragraph rotation as a function of condition. The slopes (m) were calculated using the formula:

$$m = (\hat{y}_{\text{Rotated}} - \hat{y}_{\text{Upright}})/(x_2 - x_1)$$

where $\hat{y}_{\text{Rotated}}$ is a mean response time for rotated paragraphs in a given condition (in ms), $\hat{y}_{\text{Upright}}$ is a mean response time for upright paragraphs in a given condition (in ms), and x_2 and x_1 are values of the angular deviations of the presented stimuli (60 and 0 degrees in all conditions). The slope in the Still condition (22.1 ms/degree) was significantly larger than the slope in the Free condition (11.5 ms/degree), $t(23) = 2.09$, $SE = 5.08$, $p = .047$, and the Forced Rotation condition (6.6 ms/degree), $t(23) = 3.40$, $SE = 4.55$, $p = .002$ (see Figure 5 for the slopes comparison). Additionally, the slopes in the Free and the Forced Rotation conditions were compared to zero, to determine whether there was a significant cost of rotation in those conditions. There was a significant cost of rotation in the Free condition, $t(23) = 2.57$, $SE = 4.44$, $p = .017$. The cost of rotation was not significant in the Forced Rotation condition, $t(23) = 1.69$, $SE = 3.99$, $p = .11$.

The slopes in the Free condition and the Forced rotation condition did not differ. The values of the slopes reported in Risko et al. (in press) were smaller when compared to the values in fixed condition of the current study. In the unrestricted condition those values were 0.52 ms/degree for the single letters, 5.29 ms/degree for the 5-letter arrays and 5.96 ms/degree for the 15-letter arrays. Corresponding values in the restricted condition were 1.17 ms/degree, 3.95 ms/degree and 6.92 ms/degree.

Syllables Per Minute. A number of syllables read per minute analysis was conducted in addition to the RT analysis. This was done to control for any possible influence of the different numbers of words across paragraphs. Outliers were removed based on syllables per minute. This resulted in the removal of 0.9% of responses. A 3 (Condition: Free vs. Still vs. Forced rotation) x 2 (Angular Deviation: 0 vs. 60) within subjects ANOVA was conducted. There was no main effect of condition, $F(2, 23) = 1.22$, $MSE = 131.67$, $p = .30$, $\eta_p^2 = .051$. There was a main effect of angular deviation, $F(1, 23) = 39.60$, $MSE = 87.24$, $p < .001$, $\eta_p^2 = .63$. There was an interaction between condition and angular deviation, $F(2, 46) = 7.00$, $MSE = 59.27$, $p = .002$, $\eta_p^2 = .23$. The slope of the function relating angular deviation and SPM was calculated to compare the influence of paragraph rotation as a function of condition.

The slope in the Still condition (-0.27 spm/degree) was significantly larger than the slope in the Free condition (-0.14 spm/degree), $t(23) = 2.59$, $SE = 0.049$, $p = .016$, and the slope in the Forced rotation condition (.-08 spm/degree), $t(23) = 3.70$, $SE = 0.052$, $p = .001$. The Free condition and the Forced rotation condition did not differ. The results using SPM were similar to the results when RT was used. We compared the slopes to zero, to determine whether there was a significant cost of rotation across the conditions. There was a significant effect in the Still condition, $t(23) = -6.50$, $SE = .04$, $p < .001$, and in the Free condition $t(23) = -3.56$, $SE = .04$, $p = 002$. The effect was not significant in the Forced Rotation condition $t(23) = -2.02$, $SE = .03$, $p = .054$.

Chapter 4

DISCUSSION

Why do individuals often move their bodies when solving perceptual problems? The results of the current study have demonstrated that body movements can have a functional role and act, in conjunction with the brain, as a resource available in perceptual problem solving. The comparison of performance in the Still condition with performance in the Free and Forced rotation conditions demonstrates a clear benefit of head tilting when reading rotated text. The analyses of response time and syllables per minute revealed that the cost of stimulus rotation was smaller when the participants were either free or forced to tilt their heads. In other words, the reading of the rotated paragraphs was taxed more in the Still condition, compared to the other conditions and external alignment reduced these costs. This is consistent with the idea that body movements can influence cognition and have a functional role in such a way that they can augment or replace internal processing. By using the external strategy, cognition was offloaded to the body. The current study also confirmed the expectation that the use of paragraphs would lead to a larger cost of stimulus rotation and more frequent head tilting compared to the one-, five- and fifteen-letter arrays used in previous research (Risko et al., in press). In the current study, the frequency of head tilting while reading the rotated paragraphs in the Free condition was 75.5%, while the cost of stimulus rotation was the largest in the Still condition. These findings are consistent with the idea that the increase in the internal processing effort will increase the likelihood of using the external strategies. Overall, the present results are consistent with the cognitive offloading account of external alignment.

An Alternative Account

One alternative account of the present results is that performance in the Still condition was impaired by the instructions not the rotate, rather than performance improving as a result of head rotation. This could have resulted from the instructions in the Still condition containing an additional task requirement compared to the instructions in the other conditions. Thus participants in the Still condition had to maintain a goal (i.e., keep the head in the upright position) while performing the task of reading paragraphs presented in various angular deviations. Previous studies have demonstrated that people with a low working memory capacity have difficulties maintaining a goal while performing various tasks (Unsworth & Engle, 2006). As a result, goal-maintenance in the face of distraction (e.g., an additional, simultaneous task such as reading of paragraphs) has the potential to hinder performance.

One potential response to this alternative account is that it ignores the presence of a "goal" in the Forced Rotation condition. The Forced Rotation condition, similarly to the Still condition, contained a goal-maintenance instruction (i.e., "Tilt your head in the direction of the stimuli"). However, the cost of stimulus rotation was smaller in the Forced Rotation condition compared to the Still condition, despite both containing an additional "goal" to maintain. In addition, performance in the Forced Rotation condition did not significantly differ, in terms of RT and syllables per minute, from performance in the Free condition (that did not contain an additional "goal" to maintain).

It is also interesting to consider the differences in performance between the Free and Forced Rotation condition. While there was no significant difference in performance between the Free condition and the Forced Rotation condition in terms of RT and syllables read per minute, it is worth noting that the cost of paragraph rotation was larger (and statistically significant) in the Free condition than in the Forced Rotation condition. For example, the value of the slope relating RT and angular deviation was larger in the Free condition (11.5 ms / degree) compared to the value in the Forced Rotation condition (6.6 ms /degree). This suggests that in the Free condition, the decision to tilt the head or not when reading a rotated paragraph could come at a cost (i.e., this decision was not present in the Forced Rotation condition and, of course, absent in the Still condition). This cost seems to be larger (albeit not significantly) compared to the cost of continually maintaining a to-do instruction during the task in the Forced rotation condition.

Natural Behavior

In the current study, participants were allowed to exhibit spontaneous behavior in a controlled setting. This was a critical feature of the present investigation because everyday problem solving includes a dynamic environment and frequent use of bodily solutions. Moreover, the study managed to quantify the benefits of embodiment (Clark, 2011) by demonstrating the exact beneficial effects of embodiment in terms of performance in the task of reading rotated text. This represents a step toward better understanding how external actions contribute to cognition. As such, it provides support for the future use of the natural behavior approach in the investigation of embodied cognition.

Overall, the results of the study are consistent with the idea that individuals will use the resources available to them, such as the information in the environment and body movements to avoid placing the burden of processing or storing information on the brain (Barrett 2011; Clark, 2011). Investigating natural behavior as individuals engage in cognitive tasks provides one avenue to study this behavior. It is important to note that this approach does not deny the importance of internal processes. Rather, the approach emphasized here simply admits that external processes represent an integral part of our cognitive capacities, and should be considered in the investigation of those capacities. What strategy will be adopted to solve a perceptual problem depends on the interplay of the brain, body and the environment.

Future Research

The present investigation has suggested a number of potentially interesting future research directions. For example, the current study explored head tilting as a means of external alignment. However, another means of external alignment would involve rotating the stimulus to match one's reference frame. This, of course, was not possible in the present research. While our experimental design did not allow for such a behavior to occur, this alternative mode of external alignment certainly deserves attention. For example, it would be worthwhile to explore whether there is a preference for one of these strategies over the other when faced with different perceptual tasks. This line of research provides another avenue towards understanding the embodiment of cognition. Finally, in future research it will be important to determine whether the magnitude of head tilt differentially reduces the cost of stimulus rotation. For example, do individuals who physically rotate more benefit more? As noted above, the use of motion or head tracking would likely be required for such an investigation (as opposed to video based estimation of head tilt).

Conclusion

In conclusion, the current study has demonstrated that when given the opportunity, individuals will use their bodies (i.e., tilt their head) to offload internal processing in the context of reading rotated text. This behavior can have a functional role in that it can improve performance, specifically, it can reduce the cost associated with paragraph rotation. In addition, the present investigation has raised new questions the future investigation of which will provide more insight into embodied cognition.

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APPENDIX A

FIGURES

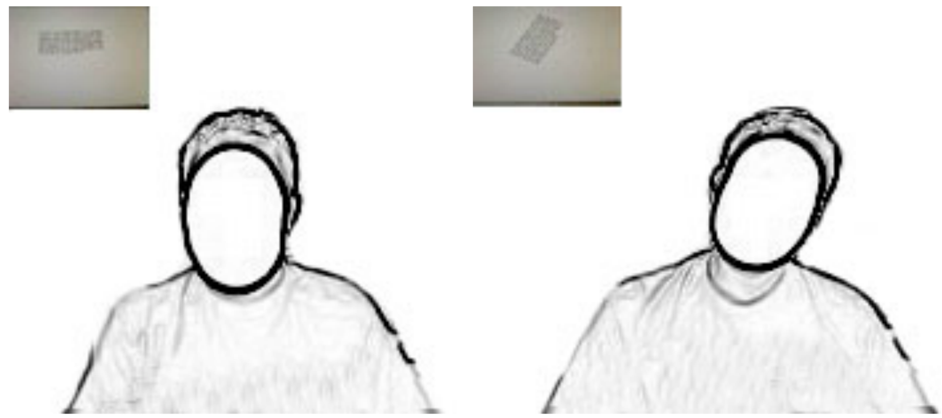

Figure 1. Example frames from participant video recordings. Stimulus image is displayed in the top left corner.

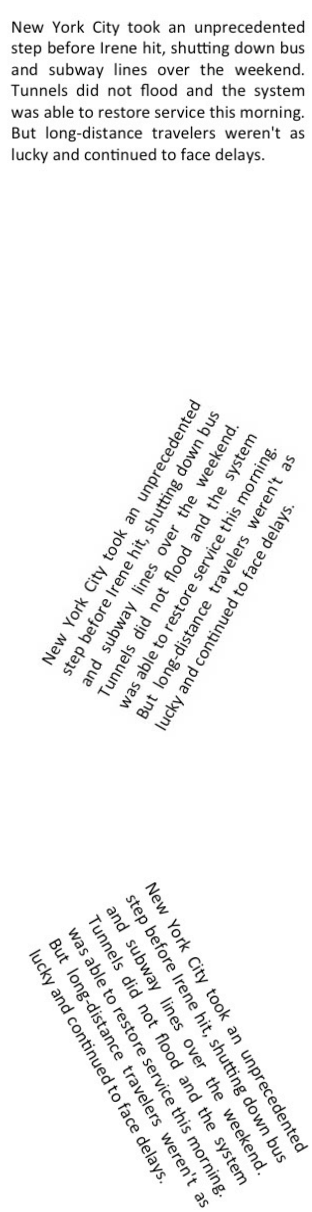

Figure 2. Examples of paragraphs upright and rotated.

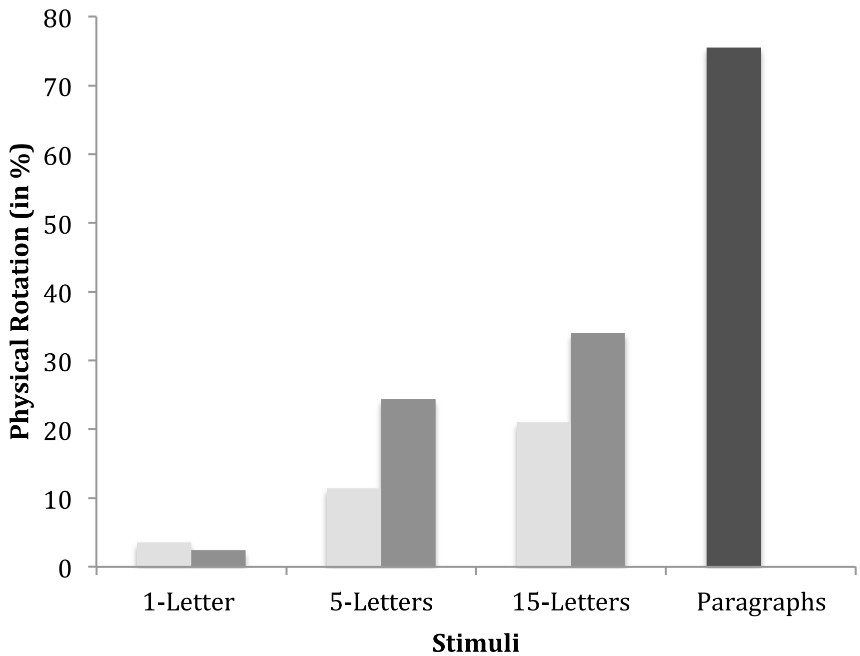

Figure 3. Comparison of physical rotation frequencies for the stimuli of different complexity. 1-Letter, 5-Letter and 15-Letter Stimuli data from Risko et al. (in press). The bars for 1-Letter, 5-Letter and 15-Letter Stimuli represent data for 45 (the left bar) and 90 degree (the right bar) stimuli rotations. Paragraphs were rotated 60 degrees. Rotated paragraphs lead to more head tilting, compared to the rotated single letters, five- and fifteen-letter arrays.

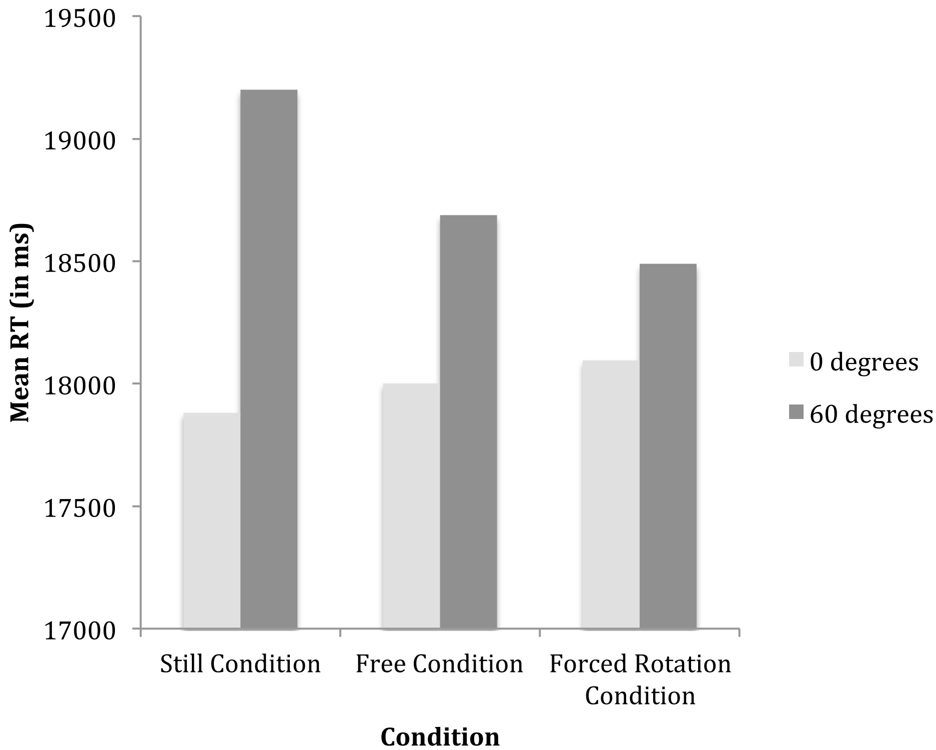

Figure 4. Response times (RT) for the reading of upright and rotated paragraphs in different conditions. The mean RTs for the upright paragraphs are similar across the conditions. However, the mean RT for the rotated paragraphs in the Still condition is larger than the corresponding values in the other conditions. Taken together, these findings indicate that the cost of stimulus rotation is the largest in the Still condition.

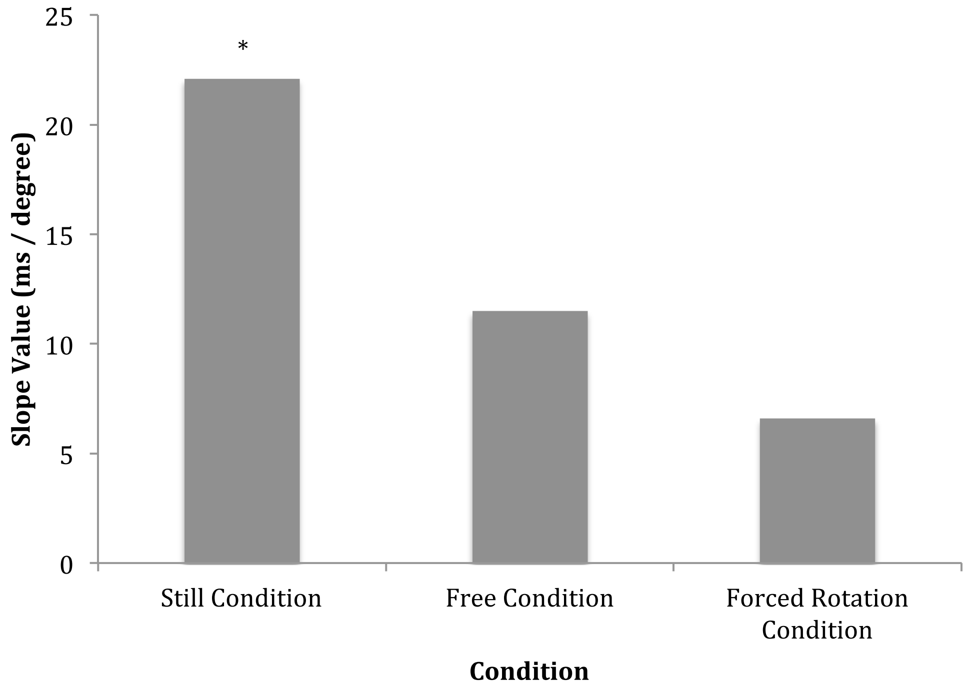

Figure 5. Values of slopes relating RT and angular deviation. The slope in the Still Condition (22.1 ms / degree) is significantly larger than the slope in the Free Condition (11.5 ms / degree) and the Forced Rotation Condition (6.6 ms /degree). The Free Condition and the Forced Rotation Condition did not differ significantly.

* Indicates a slope significantly different from the slopes in the other conditions, $p < .05$.